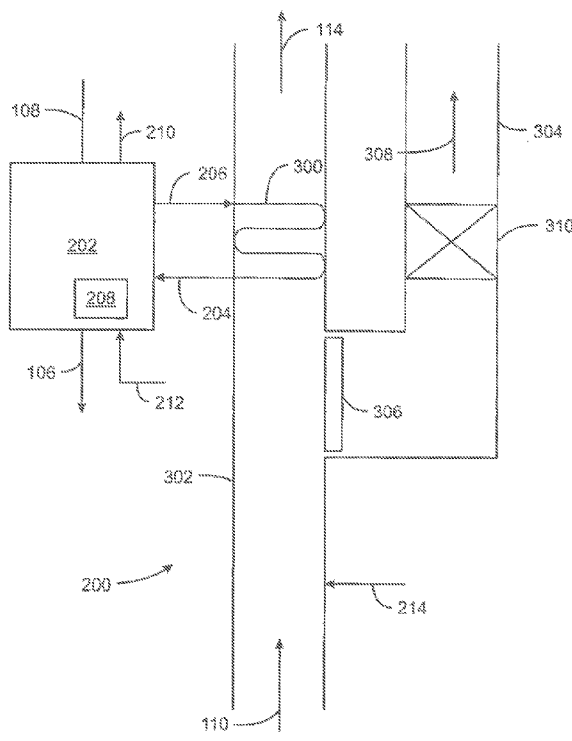




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(54) Title: HEAT RECOVERY SYSTEM AND METHOD



192
FIG. 3

(57) Abstract: The present techniques are directed to a heat recovery system, such as a waste heat recovery system (WHRU) that receives and passes a vapor across a heat exchanger (300) to transfer heat from the vapor to a heating medium in the heat exchanger. The vapor may be an exhaust gas from a source outside of the heat recovery system. The heat recovery system includes a collection system (202) to deinventory the heating medium from the heat exchanger during abnormal operation of the heat recovery system.

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HEAT RECOVERY SYSTEM AND METHOD

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit of United States patent application
5 number 62/031,720 filed July 31, 2014 entitled HEAT RECOVERY SYSTEM AND
METHOD, the entirety of which is incorporated by reference herein.

FIELD

[0002] The present techniques relate generally to heat recovery such as waste heat
recovery, and more particularly to a heat recovery system having a heating-medium
10 collection system for abnormal operation to reduce thermal degradation of the heating
medium.

BACKGROUND

[0003] This section is intended to introduce various aspects of the art, which may be
associated with exemplary embodiments of the present techniques. This discussion is
15 believed to assist in providing a framework to facilitate a better understanding of particular
aspects of the present techniques. Accordingly, it should be understood that this section
should be read in this light, and not necessarily as admissions of prior art.

[0004] Waste Heat Recovery Units (WHRU) and similar systems transfer energy from
higher temperature vapor or gas streams to a heating medium (HM) fluid, typically a liquid.
20 The HM is typically utilized as a heat source for other heat transfer equipment (users or load)
in a target or desired process. The source of the high-temperature vapor stream may be a gas
turbine, fired heater, steam generator, and other sources. The high-temperature vapor may be
a hot exhaust gas, for example, from one or more of these sources. At the WHRU, the high-
temperature vapor typically flows through ductwork or other enclosure housing coils or a
25 bundle of tubes. The HM flows through the coils or tubes and absorbs heat from the high-
temperature vapor stream passing over the coils or tubes.

[0005] In normal operation, the HM fluid typically flows through the coils or tubes at a
flow rate and relatively-short residence time that prevents excessive elevated temperature of
the HM thus may avoid significant thermal degradation of the HM or excessive deposition of
30 HM impurities, and the like. Unfortunately, during an abnormal operation or shutdown
condition, the HM flow may slow or stop. Thus, the HM fluid retained in the coils or tubes

may experience elevated temperatures and thermally degrade. Indeed, at elevated temperature over time, glycols or other similar components of the HM may form sludges having corrosive acids. Further, certain HM fluids and components, e.g., water, may exceed typical deposit rates of impurities on the tube wall at elevated temperature over time, fouling
5 the tubes.

[0006] United States Patent Application Publication No. 2011/0067742 entitled “Thermoelectric-Based Power Generation Systems and Methods” to Bell et al. describes a waste heat recovery system with a cylindrical shell that contains an exhaust fluid. Two heat exchangers extend into the cylindrical shell to exchange heat with the exhaust fluid. A
10 control valve determines when exhaust fluid may pass through the second heat exchanger.

[0007] United States Patent Application Publication No. 2011/0167865 entitled “Air-Conditioning Apparatus” to Morimoto et al. describes an air-conditioning apparatus in which the refrigerant exchanges heat with a HM in at least one intermediate heat exchanger. The document also describes the circulation systems of both the refrigerant and the HM.

15 [0008] United States Patent No. 4,669,530 entitled “Heat Exchanger Method and Apparatus” to Warner describes a dual-heat exchanger heat removal system for cooling sulfur trioxide. The design protects the first heat exchanger from corrosion by not permitting the sulfur trioxide to condense within its assembly. Furthermore, the design protects the second heat exchanger from thermal damage by cooling the sulfur trioxide in the first heat
20 exchanger.

[0009] United States Patent No. 4,737,531 entitled “Waste Heat Recovery” to Rogers describes a heat exchange unit that recovers waste heat from carbon black smoke by preheating oxygen-containing gas such as air passed to a carbon black producing reactor. A control loop is provided that automatically diverts the oxygen-containing gas being preheated
25 through a by-pass line if the temperature of the effluent smoke removed from the heat exchange is below a minimum temperature value to minimize the deposition of carbon on the heat exchange surfaces in the heat exchange zone.

[0010] United States Patent No. 6,984,292 entitled “Water Treatment for Thermal Heavy Oil” to Kresnyak et al. includes initial steps of capturing the waste heat energy from high-
30 pressure steam separator located downstream of steam generators. It further describes operating conditions that promote a 1% to about 50% mass vapor in the stream returning to

the heated separator to prevent fouling and scaling.

[0011] United States Patent No. 7,823,628 entitled “Passive Back-Flushing Thermal Energy System” to Harrison describes a thermal energy system having a heat exchanger for transferring thermal energy between a source and a load. The heat exchanger has a primary side associated with the source and a secondary side for conducting a fluid associated with the load. The secondary side of the heat exchanger is back-flushed via a specially-designed back-flush valve upon a consumption of a portion of the fluid. The abstract explains that passive back flushing prevents fouling of the heat exchanger due to sediments, scale, and mineral deposits that may be present in the circulating fluid.

10 [0012] United States Patent No. 8,470,097 entitled “Silicon-Containing Steel Composition with Improved Heat Exchanger Corrosion and Fouling Resistance” to Chun et al. describes a method of providing sulfidation corrosion resistance and corrosion induced fouling resistance to a heat transfer component surface.

[0013] A problem in a heat recovery system including a WHRU may be excessive temperature and associated thermal degradation of the HM, such as glycol, in the waste heat recovery system.

SUMMARY

[0014] An embodiment relates to a heat recovery system having a tube bundle with multiple tubes. The heat recovery system include an enclosure housing at least a portion of the tube bundle, wherein the enclosure is configured to receive a vapor and pass the vapor over the tube bundle. A pump configured to flow a heating medium through the tube bundle to one or more users. A control system is configured to detect an abnormal operation of the heat recovery system, wherein the abnormal operation includes a reduction of flow of the heating medium below a predetermined range of flow values. Lastly, the heat recovery system includes a collection system configured to reduce thermal degradation of the heating medium during the abnormal operation by evacuating the heating medium from the tube bundle during the abnormal operation.

[0015] Another embodiment relates to a waste heat recovery unit having a heat exchanger and a ductwork enclosing at least a portion of the coils, wherein the ductwork is configured to receive and pass an exhaust gas over the heat exchanger. The waste heat recovery unit includes a pump configured to circulate a heating medium through an internal flow path of

the heat exchanger to absorb heat from the exhaust gas, and wherein the pump is configured to circulate the heating medium from the waste heat recovery unit to users of the heating medium. Further, the waste heat recovery unit includes a collection system configured to remove the heating medium from the heat exchanger during an abnormal operation to reduce thermal degradation of the heating medium in the heat exchanger. The collection system includes a collection vessel configured to receive heating medium removed from the heat exchanger during the abnormal operation, and wherein the abnormal operation includes a cessation of flow or substantial reduction in a flow rate of the heating medium through the heat exchanger.

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10 [0016] Yet another embodiment relates to a method of operating a waste heat recovery unit, the method including circulating a heating medium through multiple tubes of a tube bundle in the waste heat recovery unit and to users of the heating medium outside of the waste heat recovery unit. The exemplary method includes passing a vapor over the tube bundle to transfer heat from the vapor to the heating medium. Further, the method includes
15 detecting, e.g., via a control system, an abnormal operation of the waste heat recovery unit, the abnormal operation including loss of circulation of the heating medium through the multiple tubes. Lastly, the method includes removing the heating medium from the multiple tubes to a collection vessel in the waste heat recovery unit during the abnormal operation to reduce or avoid thermal degradation of the heating medium.

20 [0017] Yet another embodiment relates to a method of constructing or retrofitting a waste heat recovery unit (WHRU) to prevent or reduce thermal degradation of heating medium during abnormal operation of the WHRU, the method including adding a conduit downstream of a tube bundle configured to transfer heat from an exhaust gas to the heating medium, wherein the conduit is configured to divert flow of the heating medium in the WHRU during
25 the abnormal operation of the WHRU, the off-specification operation including cessation of normal flow of heating medium through the tube bundle. The exemplary method includes installing a collection vessel coupled to the conduit and configured to receive heating medium drained from the tube bundle via the conduit during the abnormal operation. Lastly, the method includes installing a valve on the conduit, wherein the valve is configured to
30 isolate the collection vessel during normal operation of the WHRU and to place the collection vessel in service during the abnormal operation.

DESCRIPTION OF THE DRAWINGS

[0018] The advantages of the present techniques are better understood by referring to the following detailed description and the attached drawings, in which:

[0019] FIG. 1 is a block flow diagram of an operational system having a waste heat recovery unit (WHRU) and users of the HM circulating from the WHRU;

[0020] FIG. 2 is a block flow diagram of an exemplary WHRU of FIG. 1 having an HM collection system;

[0021] FIG. 3 is a schematic diagram of the exemplary WHRU of FIG. 2 having a tube bundle coupled to the HM collection system;

10 [0022] FIG. 4 is a simplified process flow diagram of the exemplary WHRU of FIG. 3 having an exemplary HM collection system;

[0023] FIG. 5 is a block diagram of an exemplary method of evacuating HM from a WHRU tube bundle during abnormal operation; and

15 [0024] FIG. 6 is a block diagram of retrofitting a WHRU to incorporate an exemplary HM collection system for abnormal operation.

DETAILED DESCRIPTION

[0025] In the following detailed description section, specific embodiments of the present techniques are described. However, to the extent that the following description is specific to a particular embodiment or a particular use of the present techniques, this is intended to be for exemplary purposes only and simply provides a description of the exemplary
20 embodiments. Accordingly, the techniques are not limited to the specific embodiments described below, but rather, include all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

[0026] As used herein, “substantially”, “predominately” and other words of degree are relative modifiers intended to indicate permissible variation from the characteristic so
25 modified. It is not intended to be limited to the absolute value or characteristic which it modifies, but rather possessing more of the physical or functional characteristic than its opposite, and preferably, approaching or approximating such a physical or functional characteristic.

30 [0027] “Exemplary” is used exclusively herein to mean “serving as an example, instance,

or illustration.” Any embodiment described herein as “exemplary” is not to be construed as preferred or advantageous over other embodiments.

[0028] The term “gas” is used interchangeably with “vapor,” and means a substance or mixture of substances in the gaseous state as distinguished from the liquid or solid state. Likewise, the term “liquid” means a substance or mixture of substances in the liquid state as distinguished from the gas or solid state. As used herein, “fluid” is a generic term that may include liquid and either a gas or vapor.

[0029] Embodiments of the present techniques are directed a thermal energy system such as a heat recovery system, waste heat recovery unit (WHRU), or similar system. The thermal energy system has a heat exchanger for transferring thermal energy between thermal energy content and a load. The thermal energy content may include a high temperature vapor, such as an exhaust gas, while the load may include a heat transfer fluid, a HM, and the like. The high-temperature vapor may be provided or produced by gas turbines, fired heaters, steam generators, and so forth.

[0030] In examples, the heat exchanger has a primary side associated with the high-temperature vapor, and a secondary side for receiving and outputting the load, e.g., the secondary side receives a fluid to be heated and outputs a heated fluid. The heat exchanger may reside, for instance, in a ductwork or other enclosure transporting the energy source fluid. As discussed below, auxiliary equipment and a control system may provide for shutdown conditions and evacuation of the secondary side, e.g., tube-side, of the heat exchanger.

[0031] A bundle or coils of tubes may form the assembly of the heat exchanger transferring energy between the high-temperature vapor and load fluids. The tubes of the bundle, or coil of tubes, of the heat exchanger may be plain, externally finned, internally finned, continuously finned and may possess numerous other heat-transfer enhancements or features. The conduits or tubes of the bundle/coil of tubes may have a downward slope to aid drainage of HM fluid. The upward movement or escape of formed HM fluid vapor may also be assisted. The HM will generally exchange energy with the high-temperature vapor while remaining in the liquid phase. The system may include tanks, valves, and associated piping to evacuate the HM fluid from the heat exchanger in the case of failed circulation of the HM fluid.

[0032] Further, air or ambient air may be introduced during the shutdown period to reduce the temperature of the high-temperature vapor flowing across the primary side, e.g., the exterior, of the heat exchanger. The reduced temperature from the introduction of air may decrease the thermal degradation of the HM fluid on the secondary side of the heat exchanger. The system may also introduce an inert gas purge through the tube side of the heat exchanger to remove any residual heating-medium film on the inner surface of the secondary side of the heat exchanger. This may also mitigate the formation of a solid and corrosive fouling layer on either side of the heat exchanger, due to oxidation.

[0033] In the WHRU's transfer of energy from higher temperature vapor streams to a HM fluid, typically a liquid, the HM may be utilized as a heat source for other heat transfer equipment, such as users or other loads, in a desired or target process. As discussed, in the WHRU, the high-temperature vapor that is carried in the ductwork typically passes over a bundle of tubes or coils through which the HM fluid flows. Various physical states and compositions of the HM fluid may be employed but the HM fluids may generally thermally degrade or deposit impurities or scale when maintained at excessive elevated temperatures over time. Thermal degradation of glycols, for example, a component of certain HM fluids, may form sludges of corrosive acids. With continued exposure to the effects of the high-temperature vapor on the outer tube wall, the formed corrosive sludge may continue to degrade and transform into a substantially solid layer of material on the inner tube wall. The solid material may negatively affect the mechanical integrity and operational performance of WHRU tube bundle and associated process equipment or users of the HM.

[0034] In normal operation, the HM fluid flows inside the tubes at a rate that may substantially avoid thermal degradation of the HM fluid, including at the inner tube wall that typically exhibits the highest temperature in the tubes. However, during off-specification or abnormal operating conditions, the HM fluid flow inside the tubes may slow or even stop. If the tube bundle remains full of stagnant HM fluid exposed to the high-temperature vapor flow, thermal degradation of the HM fluid inside the tubes may begin, for example, starting at the inner tube wall. Again, the thermal degradation may lead to the formation of corrosive sludge that negatively impacts and reduces the mechanical integrity of the tubes, and may lead to formation of an associated fouling layer that generally worsens the performance of the WHRU. Off-specification or abnormal operating conditions may result in a reduction of or stopped HM fluid circulation flow, higher vapor temperatures than design on the outside of

the tubes, and failure of a control damper within the WHRU assembly to divert the high-temperature vapor flow away from the tube bundle when desired, and so forth. In the event that the HM circulation decreases below an acceptable range and the high-temperature vapor is not diverted away from the WHRU coils either by design or system failure, the described apparatus and generalized strategy of its operation is expected to protect the HM from thermal degradation and, therefore, protect its associated equipment.

[0035] FIG. 1 is a block flow diagram of an operational system **100** having a heat recovery unit such as a waste heat recovery unit (WHRU) **102**. In general, a WHRU recovers heat from hot exhaust vapor in the system **100** before discharging the hot exhaust vapor. In the recovery, the WHRU transfers heat from the incoming hot exhaust vapor to a heat-transfer fluid. Thus, the recovered heat is used to increase the temperature of the heat-transfer fluid. The heated heat-transfer fluid may be supplied as a utility HM to process equipment in the system **100**.

[0036] In operation in the illustrated embodiment, the HM circulates through the WHRU **102** to absorb heat from hot exhaust vapor and then through one or more users **104** in the system **100** to provide heat to the users **104**. The users **104** may be heat exchangers or other types of equipment that absorb heat from the HM. The overall system **100** may be an industrial, commercial, or public facility or complex involved in the manufacturing, production, processing, treatment, handling, and so forth, of one or more products (not shown).

[0037] In embodiments, the WHRU **102** circulates the HM through a heat exchanger to absorb heat from an incoming hot exhaust vapor to provide a HM supply **106** to the users **104**. The WHRU **102** receives a HM return **108** from the users **104**. The HM return **108** is typically cooler than the HM supply **106**. Again, the users **104** may be heat exchangers or other process equipment that absorb heat from the HM supply **106**.

[0038] In some embodiments, the WHRU **102** receives a vapor **110** from one or more sources **112**, and discharges a cooled vapor **114**. The cooled vapor **114** may be discharged to atmosphere or to a recovery system, and so on. The inlet vapor **110** is generally a high-temperature vapor, such as a hot exhaust gas, and the like. The sources **112** of the inlet vapor **110** may be gas turbines, fired heaters, steam generators, and other sources of hot vapor or gas. In examples, the inlet vapor **110** may be waste gas from the source **112**. An exemplary temperature range of the inlet vapor **110** is about 300 °C to about 800 °C. An exemplary

temperature range of the cooled vapor **114** discharging from the WHRU **102** is about 200 °C to about 550 °C. Of course, other temperature range values for the inlet vapor **110** and the cooled vapor **114** are applicable. In certain embodiments, the inlet vapor **110** is a discharge or exhaust gas or vapor from one or more sources **112** outside of the WHRU **102**. In other words, the WHRU **102** may be a utility system that receives inlet vapor **110** from process or production systems or other utility systems. In fact, the WHRU **102** may be a shared utility in the overall system **100** at a facility or site, for example. As appreciated by one of ordinary skill in the art, the WHRU **102** may be a utility system outside the battery limits of the source(s) **112**. Indeed, in examples, the WHRU **102** may be an outside battery limits (OSBL) system to the source(s) **112**.

[0039] Further, the overall system **100** and/or WHRU **102** may include a control system **116**, such as a distributed control system (DCS), programmable logic controller (PLC), and so on. The control system **116** may have a human interface (HMI) and facilitate control of the system **100** including the WHRU **102**. The control system **116** may direct operation of equipment, control valves, and the like, in the WHRU **102**. The control system **116** may include instrumentation, computers, computer memory, a processor, and so forth. The control system **116** may include logic or code stored in memory and executable by the processor to implement or facilitate the control actions disclosed herein. Lastly, as discussed below, the WHRU **102** may include a shutdown HM collection system (that may work in concert with the control system **116**) to reduce thermal degradation of the HM during abnormal operations of the WHRU **102**.

[0040] FIG. 2 is a block flow diagram of an exemplary WHRU **102** of FIG. 1 having an exhaust stack **200** and a HM collection system **202**. Like numbered items are as described with respect to FIG. 1. The exhaust stack **200** may house a heat exchanger (not shown) having coils or a tube bundle to transfer heat from the inlet vapor **110** to a HM, e.g., to provide a heated HM supply **106**. The HM collection system **202** is coupled to the tube bundle in the stack **200** via a first or supply conduit **204** and a second or return conduit **206**. As discussed below, the supply conduit **204** and return conduit **206** may accommodate bi-directional flow during abnormal operation.

[0041] The HM collection system **202** may both facilitate circulation of the HM including during normal operation, and facilitate the evacuation and collection of HM from the heat-exchanger tubes or coils in the stack **200** during a shutdown or abnormal operation. The HM

collection system **202** may include the pump and hydraulic expansion vessel that circulates the HM. Thus, the HM collection system **202** may provide the HM supply **106** to users **104** (FIG. 1) and receives the HM return **108** from the users **104**. In the illustrated embodiment during normal operation, the HM supply **106** flows through the supply conduit **204** from the tube bundle or coils in the stack **200**, and the HM return **108** flows through the return conduit **206** to the tube bundle of coils in the stack **200**.

[0042] During abnormal operation with the HM circulation slowing or stopping, and with the high-temperature vapor **110** continuing to flow across the heat-exchanger tubes or coils in the stack **200**, the HM collection system **202** may facilitate evacuation of the HM from the tube coils in the stack **200**. The evacuation of the HM from the tube coils may reduce thermal degradation of the HM during the shutdown or abnormal operation.

[0043] In some configurations, the HM collection system **202** includes a collection vessel **208** to accumulate HM drained via the supply conduit **204** from the coils during the abnormal or off-specification operation. The collection vessel may be sized to at least the volume of the heat-exchanger tubes or coils in the stack **200**. Also, in certain examples, any vaporized HM from the coils during the off-specification operation may flow through the return conduit **206** to the HM collection system **202**. If desired, the HM vapor may further discharge through a vent **210** from the collection system **202**.

[0044] Additionally, the HM collection system **202** may flow an inert gas **212** purge through the coils or tubes in the stack **200** via the supply conduit **204**, for example, to facilitate removal of residual HM film from the inner surface of the coils or tubes. The purge may reduce the formation of a solid and corrosive fouling layer in the tubes. Moreover, a gas **214** such as ambient air may be introduced into the stack **200** during the abnormal operation or off-specification operation to reduce the temperature of inlet vapor **110** flowing across the tubes or coils in the stack **200**. Thus, the introduction of the gas **214** may contribute to the reduction of the thermal degradation of the HM fluid in the tubes or coils. Lastly, the WHRU **102** may employ the control system **116** to facilitate implementation of the HM evacuation from the tubes and the associated aforementioned operations. For example, abnormal operation may include a shutdown or a decrease in flow that may cause the HM fluid to reach temperatures that may result in degradation. Accordingly, a measurement of the temperature of the HM may be used to determine whether the HM needs to be drained from the coils, alone or in combination with other indications, such as a failure of a circulation pump.

[0045] FIG. 3 is a schematic diagram of the exemplary WHRU **102** of FIGS. 1 and 2 having a heat exchanger as a tube bundle **300** in the stack **200**. Like numbered items are as described with respect to FIGS. 1 and 2. The tubes or coil of tubes of the bundle **300** of the heat exchanger may be plain, externally finned, internally finned, continuously finned and
5 may possess other heat-transfer enhancements or features. The WHRU **102** may have one or more heat exchangers, each having respective tube bundles **300**, disposed in series, parallel, or both.

[0046] In the illustrated embodiment, the tube bundle **300** is disposed in a primary stack **302** and coupled to the HM collection system **202**. The coupling provides for operational or
10 fluidic coupling of the HM collection system **202** to the tube-side of the tube bundle **300**. The stack **200** includes the primary stack **302** and a bypass stack **304**. The primary stack **302** and the bypass stack **304** may be ductwork and/or other types of enclosures and conduits. If ductwork is employed, the ductwork may be a series of ducts. As appreciated by the skilled artisan in this context, a duct may be an enclosure, conduit, tube, or pipe for conveying the
15 vapor **110**. The material of construction of the ductwork may be selected for relatively high temperature to accommodate the temperature of the vapor **110**. In certain embodiments with the primary stack **302**, the ductwork or portions of the ductwork conveys vapor **110** or other fluids across the tube bundle **300**, and also houses or encloses, or partially encloses, the tube bundle **300**.

[0047] The primary stack **302** is generally employed during typical operation, whereas the bypass stack **304** may generally be placed in operation during atypical operation. To activate the bypass stack **304** in the illustrated embodiment, a damper **306** may be opened to divert vapor **110** flow from the primary stack **302** to the bypass stack **304**. The diverted vapor **110** may discharge from the bypass stack **304**, as indicated by arrow **308**, to the
25 atmosphere or for additional processing. In embodiments, the bypass stack **304** may include various operational units **310**, such as a silencer or exhaust treatment catalyst bed.

[0048] As mentioned, the primary stack **302** houses the tube bundle **300**. The inlet vapor **110** enters the primary stack **302** and passes across the tube bundle **300**. The WHRU **102** employs the tube bundle **300** to transfer heat from the vapor **110** to the HM flowing through
30 the tubes of the tube bundle **300**. A cooled vapor **114** flowing from across the tube bundle **300** discharges from the primary stack **302** to the atmosphere or additional processing.

[0049] The HM having absorbed heat from the vapor **110**, and thus, a higher temperature,

discharges from the tube-side of the tube bundle **300** into the supply conduit **204** and is provided as HM supply **106** to users **104** (FIG. 1). The HM return **108** from the users **104** flows through the return conduit **206** to the tube-side of the tube bundle **300** to be reheated in the tube bundle **300**.

5 [0050] During an abnormal operation, such as a pump failure or system shutdown that involves the HM circulation slowing or discontinuing, the HM collection system **202** may facilitate evacuation of HM from the tube-side of the tube bundle **300**. Such evacuation may reduce thermal degradation of the HM during the shutdown or abnormal operation, especially while the high-temperature vapor **110** is continuing to flow across the tube bundle **300** during
10 the abnormal operation. The continued flow of the high-temperature vapor **110** across the tube bundle **300** may be intended or by design, or may be due to mechanical failure or faulty operation of the damper **306**, problems with the bypass stack **304**, and so forth.

[0051] As discussed, the HM collection system **202** may include a collection vessel **208** to accumulate HM drained via the supply conduit **204** from the tube bundle **300** during the
15 abnormal or off-specification operation. The tube bundle **300** and the supply conduit **204** may be configured (e.g., a mild slope) to facilitate flow or draining, e.g., via gravity, of the HM from the tube bundle **300** to the collection vessel **208**.

[0052] In some embodiments, a back-flushing of the tube bundle **300** to displace or remove HM from the tube bundle **300** is not required. Indeed, certain embodiments of the
20 HM collection system **202** are configured wherein back-flushing is not employed to remove HM from the tube bundle **300** during the abnormal operation.

[0053] Moreover, any vaporized HM from the tube bundle **300** during the shutdown or off-specification operation may flow from the tube bundle through the return conduit **206** to the HM collection system **202** and discharge as a vent **210**. This HM vapor flow (if present)
25 is generally in the opposite direction of the typical HM return **108** liquid flow through the return conduit **206** during normal operation.

[0054] As also mentioned, the HM collection system **202** may include piping to introduce an inert gas **212** into the tube-side of the tube bundle **300** via the supply conduit **204** or other conduit. The purging of the tubes with the inert gas **212** may facilitate removal of residual
30 HM film from the inner surface of the coils or tubes, reduce formation of a solid and corrosive fouling layer in the tubes, and the like. In examples, the inert gas **212** may flow

through supply conduit **204** (in opposite direction of normal flow of the HM supply **106**), through the tubes of the tube bundle **300**, and then through the return conduit **206** (in opposite direction of normal flow of the HM return **108**) to be discharged from the HM collection system **202** in the vent **210**.

5 [0055] FIG. 4 is a simplified process flow diagram of the exemplary WHRU **102** of FIGS. 1-3 having an exemplary HM collection system **202**. In this example, the HM collection system **202** is coupled to the tube bundle **300** via the supply conduit **204** and return conduit **206**. In the illustrated embodiment, the HM collection system **202** drives both circulation of HM during normal operation and the collection of HM from the tube bundle
10 **300** (e.g., to a HM collection vessel **208**) during certain abnormal operations of the WHRU **102**.

[0056] The HM collection system **202** includes a HM expansion vessel **402** and a pump **404** to circulate the HM including during normal operation. The pump **404** provides a motive force to circulate the HM through the HM circuit including through the tube bundle **300** and
15 the users **104**. In examples, the pump **404** is a centrifugal pump. The HM expansion vessel **402** accommodates thermal expansion of the HM flowing through the hydraulically-full HM circuit. In particular, the liquid level **406** in the expansion vessel **402** may rise and fall to account for thermal expansion of the HM in the circuit.

[0057] A vent valve **408**, such as a control valve, pressure control valve, or flow control
20 valve, among others, which is located on the expansion vessel **402** overhead may be modulated to prevent excessive accumulation of uncondensed components in the system and to control pressure of the expansion vessel **402** to a desired pressure set point. The valve **408** may vent noncondensable or uncondensed components, as vent **210**, that accumulate in the circuit. In operation, the vent valve **408** may modulate the flow rate of a vent **210** stream
25 from the vapor space of the expansion vessel **402** to control pressure in the expansion vessel **402**, and thus, facilitate control of suction pressure of the HM circulating pump **404**.

[0058] In the illustrated embodiment, the expansion vessel **402** receives the HM return **108**
30 **108** from the users **104** (FIG. 1). The HM return **108** flows from the expansion vessel **402** via pump suction piping **410** to the pump **404**. The pump **404** discharges the HM return **108** through pump discharge piping **412** and return conduit **206** to the tube-side of the tube bundle **300** in the primary stack **302**. Isolation valves may be disposed around the circulation pump **404** on the suction piping **410** and the discharge piping **412**, respectively. In the illustrated

example, an isolation block valve **416** is disposed on the pump discharge piping **412**. The valve **416** may additionally be a modulating control valve to adjust flow rate of the HM. On other hand, in the case of the valve **416** as only an isolation valve, an additional valve (not shown) as a control valve may be disposed on the pump discharge piping **412** or the return
5 conduit **206** to modulate the flow rate of the HM. Any such control valves, as well as pump recirculation line **418** and recirculation valve **420**, may promote hydraulic stability of the pump **404** operation. Typically, the pump **404** provides motive force in the HM circulation for transport of the HM supply **106** from the WHRU **102** to the users **104**. In operation, the HM supply **106** flows from the tube bundle **300** through the supply conduit **204**, supply
10 piping **422**, and any supply valves **424** and **426** on the supply piping **422**, to the users **104**.

[0059] As discussed, removal of the HM fluid from the tube-side of the tube bundle **300** may be implemented during certain abnormal operations of the WHRU **102** to avoid or reduce thermal degradation of the HM. To implement such removal, an HM collection vessel **208** disposed on the downstream side of the tube bundle **300** may be placed in service, such
15 as by opening valves **428** and **430**, e.g., block valves, around the collection vessel **208**. Of course, other valve and piping configurations to place the collection vessel **208** in operation may be applicable. Moreover, in some embodiments, one or more optional valves **424** and **426** on the piping **422** that transports the HM supply **106** to users during normal operation may be closed in the shutdown or off-specification scenario.

20 [0060] Typically, during normal operation, the HM collection vessel **208** is isolated, e.g., with valves **428** and **430** in a closed position, and is not utilized during normal operation of the WHRU **102**. Again, the HM supply **106** during normal operation flows through supply piping **422** and with any supply valves **424** and **426** in an open position. However, as mentioned, during an abnormal operation of the WHRU **102**, the collection vessel **208** and
25 collection piping **432** placed in service to receive HM fluid from the tube bundle **300** to the collection vessel **208** via the supply conduit **204** and collection piping **432**.

[0061] Indeed, in abnormal operation where the circulating HM fluid slows or stops, such as due to a pump **404** failure, and which may include examples with the high-temperature inlet vapor **110** continuing to flow across the tube bundle **300**, the HM fluid may be
30 evacuated from the tube bundle **300** to the collection vessel **208**. Otherwise, the stagnant HM fluid in the tube bundle **300** may reach elevated temperatures and thermally degrade. Therefore, in such abnormal conditions, the HM fluid may be removed, e.g., drained, to the

collection vessel **208** via collection piping **432**.

[0062] As indicated, to place the collection vessel **208** in service, at least one block valve around the collection vessel **208** may be opened. In the illustrated embodiment, to place the collection vessel **208** in operation, an inlet valve **428** to the collection vessel **208** and an outlet valve **430** from the collection vessel **208** may each be opened. Thus, a collection
5 conduit or collection piping **432** and the collection vessel **208** are placed in service for the abnormal operation and to remove HM from the tube bundle **300**. Further, in addition to the collection vessel **208** and collection piping **432** placed in operation to receive HM fluid evacuated or drained from the tube bundle **300**, one or more valves **424** and **426** (if present)
10 on the HM supply **106** piping **422** to the users **104** may be optionally placed in a closed valve position.

[0063] Further, in embodiments, HM fluid vaporized (if present) in the tube bundle **300** may be removed. For example, such HM vapor may flow through return conduit **206** and recirculation line **418** to the expansion vessel **402**, and discharged by the vent valve **408**.
15 Moreover, it should be noted that if a pump recirculation line **418** is not included in the WHRU **102**, a similar line **418** and valve **420** may be installed to provide a route for HM vapor to reach the vapor space of the expansion vessel **402** from the tubes or coils during the abnormal operation. In addition, an inert gas **212** may be purged through the tube bundle **300**. The inert gas **212** may reach the tube bundle **300** through the supply conduit **204**, for
20 example. Of course, other various pipes or conduits may be utilized to introduce the inert gas **212** purge through the tube bundle **300**.

[0064] Thus, in an event that the HM circulation rate decreases below an acceptable value, the aforementioned techniques may protect the HM fluid from substantial thermal degradation. This may be especially useful if the high-temperature vapor, e.g., hot exhaust
25 gas, is not diverted from the WHRU tubes or coils. This shutdown technique may reduce fouling of the WHRU coil or tubes, and also users of the HM from the WHRU.

[0065] A control system may be configured to detect an abnormal operation of a heat recovery system or the WHRU, wherein the abnormal operation may include a reduction of flow of the HM below a predetermined range of flow values. An inadvertent or intentional
30 shutdown of the circulation pump **414** may be the cause of the reduced or no circulation flow in the abnormal operation. An inadvertent shutdown of the pump **414** may involve an operational mistake and/or equipment failure. Again, the pump **414** may be a pump

configured to flow a HM through the tube bundle **300** to one or more users.

[0066] In one example of abnormal operation, the HM circulation pump **404** may be electrically tripped and thus stopped. In other words, the electrical supply to the motor of the pump **404** is stopped and thus the pump **404** does not provide a motive force for flow of the
5 HM through the tube bundle **300**. This represents a viable cause of reduced HM circulation rate and/or cessation of HM circulation. Of course, other causes may result in a reduced or ceased HM circulation.

[0067] To implement a shutdown and HM evacuation technique to reduce thermal degradation of the HM in the tube bundle **300** or coils, the pump **404** may be isolated from
10 the HM fluid in the tube bundle **300**. Further, the recirculation valve **420** may be placed in an open or full open position to facilitate any potentially expanding HM liquid or vapor in the tube bundle **300** to travel in a reverse flow direction through the return conduit **206**. HM vapor generated in the tube bundle **300** during the abnormal operation and shutdown may pass through the recirculation valve **420** and out through the vent valve **408** as needed.
15 Optionally, a block valve **434** may be employed to the users from the HM expansion vessel **402** during the shutdown period.

[0068] With the flow of the primary HM fluid circuit stopped, and potentially blocked via the valve **434** at the expansion vessel **402**, the valve **428** to the HM collection vessel **208** may be opened to facilitate HM fluid inventory within the tube bundle **300** to drain freely (by
20 gravity) into the HM collection vessel **208**. Opening this side stream to the collected vessel **208** may reduce the amount of time the HM fluid is subject to the harsh process conditions in the tube bundle **300**, such as with continuation of the high-temperature vapor **110** flowing over tube bundle **300** while the pump **404** is shut down and with no normal flow of HM through the tube bundle **300**. This opening of the valve **428** to the collection vessel **208** may
25 reduce the vaporization of the HM fluid, the degradation of the HM fluid, and the formation of corrosive sludge in the non-flowing HM fluid, and so on. The tubes of tube bundle **300** may possess a downward slope to aid downward HM fluid liquid drainage to the HM collection vessel **208** and facilitate upward escape of formed HM fluid vapor escape to the HM expansion vessel **402** in this shutdown arrangement.

[0069] A gas **212** such as ambient air may be introduced into the stack **302** during the
30 shutdown period to dilute and lower temperature of the high-temperature vapor **110**, e.g., hot exhaust gas, flowing over the tube bundle **300**. Such ambient air introduction may aid the

mitigation of the thermal degradation of the HM fluid within the tube bundle **300** during the off-specification operation and shutdown period. Furthermore, the aforementioned inert gas **212** purge may pass through the tubes of the tube bundle to assist in purging any film of HM fluid that remains on the inside walls of the tubes.

5 [0070] Lastly, these exemplary configurations specifically related to exemplary valve and equipment arrangements are not meant to limit the present techniques. Other arrangements within the scope of the present techniques may implemented to circulate the HM, and also to reduce HM fluid thermal degradation and associated damage to equipment in response to various abnormal operation and circuit shutdown causes.

10 [0071] For example, the pump **404** may be located on the HM return portion of the circuit before the inlet to the coils or tube bundle **300**, as shown, or may instead be disposed on the HM supply portion of the circuit after the outlet of the tube bundle **300**. Indeed, in some embodiments, the pump **404** may generally be disposed at locations throughout the HM system and circuit. Further, in certain examples, the pump **404** may not be a component of
15 the collection system **202** but instead be disposed outside of the collection system **202**. Furthermore, in some embodiments, the collection vessel **208** may be generally in addition to the expansion vessel **402**, as shown, wherein the collection vessel is not the expansion vessel. Moreover, the HM flow through the coils or tube bundle **300** may be downward or upward with respect to ground. Also, the enclosure or primary stack **302** routing the inlet vapor **110**
20 may be vertical, horizontal, or inclined, or any combination thereof.

[0072] FIG. 5 is a block diagram of a method **500** of operating a heat transfer system such as a waste heat recovery unit. At block **502**, the method includes circulating a HM through multiple tubes or coils of a tube bundle in a waste heat recovery unit and to users of the HM. At block **504**, the method includes passing a vapor over the tube bundle to transfer
25 heat from the vapor to the HM. The vapor may be an exhaust gas from an upstream source.

[0073] At block **506**, the method includes detecting, e.g., via a control system, an abnormal operation of the waste heat recovery unit. The abnormal operation may include loss of normal circulation of the HM through the multiple tubes or coils, an excessive temperature of the HM in or exiting the tube bundle, and so on. For instance, the HM flow
30 may slow or stop through the tubes. In examples, the loss of circulation of the HM is caused by the failure or shutdown of a pump that circulates the HM. Further, the abnormal operation may include continued flow of the vapor over the tube bundle or coils. In some

circumstances, the reduced flow may be caused by an operational error from a user **104** (FIG. 1), for example, closing a valve in a separate process unit.

[0074] At block **508**, the method includes evacuating the HM from the multiple tubes or coils to a collection vessel during the abnormal operation to reduce thermal degradation of the HM. The waste heat recovery unit has a HM collection system having the collection vessel. Evacuating of the HM may include draining by gravity the HM from the multiple tubes to the collection vessel. The evacuation of the HM may substantially deinventory or evacuate the HM from the multiple tubes or coils. Moreover, the evacuating of the HM from the tubes or coils may include venting HM vaporized in the multiple tubes or coils during the abnormal operation.

[0075] At block **510**, the method may include diluting the vapor with air to reduce temperature of the vapor during the abnormal operation. The air may be ambient air introduced into the enclosure or ductwork receiving the vapor and housing the tube bundle. At block **512**, the method may include purging the multiple tubes or coils with an inert gas during the abnormal operation.

[0076] FIG. 6 is a block diagram of a method **600** of constructing or retrofitting a waste heat recovery unit (WHRU) to reduce thermal degradation of HM during abnormal or off-specification operation of the WHRU. In particular, the method **600** may involve construction of a new WHRU or retrofit of an existing WHRU to provide for deinventory or evacuation of HM from tubes or coils in the WHRU during off-specification or abnormal operation to reduce thermal degradation of the HM. For example, the new construction or retrofit may allow HM in the tubes or coils to be drained during the abnormal operation. At block **602**, the method includes adding a conduit downstream of a tube bundle in the WHRU that transfers heat from an exhaust gas to the HM, wherein the conduit to divert flow of the HM in the WHRU during the abnormal operation of the WHRU. The abnormal operation may include cessation of normal flow of HM through tubes or coils of the tube bundle, such as with shutdown or failure of a HM circulation pump, closure of a valve on the HM circuit, and so forth. At block **602**, the method includes installing a collection vessel coupled to the conduit and to receive HM drained from the tube bundle via the conduit during the abnormal operation. The collection vessel may be sized to hold at least the amount of HM in the tubes or coils of the tube bundle during normal operation. Moreover, the collection vessel and associated piping and valves, may be carbon steel, stainless steel, nickel alloys, exotic metals,

fiberglass reinforced plastic (FRP), and so forth. At block **604**, the method includes incorporating a valve on the conduit to facilitate isolating the collection vessel during normal operation of the WHRU and to facilitate placing the collection vessel in service during the abnormal operation. For example, the valve (see, e.g., valve **428** in FIG. 4) in a closed position may isolate, at least in part, the collection vessel during normal operation of the WHRU, and the valve in an open position may facilitate the collection vessel to be placed in service during the abnormal operation of the WHRU. At block **606**, the method includes installing an inert-gas purge inlet to provide an inert gas purge (e.g., nitrogen) through tubes or coils of the tube bundle during the off-specification operation. At block **608**, the method includes installing another conduit to receive vaporized HM from the tube bundle during off-specification operation. At block **610**, the method includes installing an ambient-air inlet on ductwork receiving the exhaust gas and housing the tube bundle. Lastly, at block **612**, the method may include integrating or programming a control system (e.g., DCS, PLC, etc.) to detect the abnormal or off-specification operation, and to automatically implement operation of the aforementioned features. To do so, the control system may have a processor and code or logic stored on memory and executable by the processor. The control system via instrumentation may detect, for example, a HM circulation flow rate falling below a predetermined value, an “off” operation of the HM circulation pump, a HM temperature above a predetermined value, and so forth. In response, the control may be configured (including programmed) to automatically adjust opening positions of valves to place the collection in service to drain HM liquid from the tubes or coils.

[0077] In summary, Waste Heat Recovery Units (WHRU) and similar systems transfer energy from higher temperature vapor or gas streams to a HM fluid, typically a liquid. The HM is generally utilized as a heat source for other heat transfer equipment (users or load) in a target process. The source of the high-temperature vapor stream may be a gas turbine, fired heater, steam generator, and other sources. At the WHRU, the high-temperature vapor typically flows through ductwork or other enclosure housing coils or a bundle of tubes. The HM flows through the coils or tubes and absorbs heat from the high-temperature vapor stream passing over the coils or tubes.

[0078] In normal operation, the HM fluid may flow through the coils or tubes at a flow rate that provides a relatively-short residence time, which prevents excessive elevated temperature of the HM, significant thermal degradation of the HM, excessive deposition of

HM impurities, and the like. Unfortunately, during an abnormal operation or shutdown condition, the HM flow may slow or stop. Thus, the HM fluid in the coils or tubes may experience elevated temperatures and thermally degrade. Indeed, at elevated temperature over time, glycols or other similar components of the HM may thermally degrade to corrosive acids and sludge. Further, certain HM fluids and components, e.g., water, at elevated temperatures over time may exceed typical deposit rates of impurities on the tube wall, fouling the tubes.

[0079] In conclusion, embodiments herein may provide for a heat recovery system with a tube bundle having multiple tubes or coils. The system includes an enclosure (e.g., ductwork) housing at least a portion of the tube bundle, wherein the enclosure to receive and pass a vapor over the tube bundle. The vapor may be hot exhaust gas from an upstream source. The system includes a pump to circulate a HM through the multiple tubes or coils to absorb heat from the vapor, and the pump to circulate the HM to users of the HM. A control system is employed to detect an abnormal operation of the heat recovery unit, the abnormal operation including a cessation or substantial reduction of a flow rate of normal flow of the HM through the multiple tubes. The abnormal operation may involve a shutdown of the pump. Further, the abnormal operation may include continued flow of the vapor across the tube bundle in the enclosure.

[0080] The heat recovery system includes a collection system to deinventory or evacuate the HM from the multiple tubes during the abnormal operation to reduce thermal degradation of the HM during the abnormal operation. The collection system may include a collection vessel to accumulate the HM removed from the multiple tubes during the abnormal operation. The collection vessel may be sized to hold at least the amount of HM in the multiple tubes during normal operation. The collection system may also receive and vent HM vaporized in the multiple tubes during the abnormal operation. Additionally, the collection system may have an inert gas inlet to provide an inert gas purge through the multiple tubes during the abnormal operation. Also, the heat recovery system may have an ambient air inlet on the enclosure to introduce ambient air into the enclosure to dilute and reduce temperature of the vapor during the abnormal operation.

[0081] Other embodiments provide for a WHRU having a heat exchanger (e.g., coils, tube bundle, tubes, etc.) and ductwork enclosing at least a portion of the heat exchanger, wherein the ductwork to receive and pass an exhaust gas over the heat exchanger. The

WHRU includes a pump to circulate a HM through an internal flow path of the heat exchanger to absorb heat from the exhaust gas, and the pump to circulate the HM to users of the HM. Further, the WHRU includes a collection system to remove the HM from the coils during an abnormal operation to reduce thermal degradation of the HM in the heat exchanger.

5 The collection system has a collection vessel to receive HM removed from the heat exchanger during the abnormal operation. The collection system typically includes a conduit to drain by gravity the HM from the heat exchanger to the collection vessel. The abnormal operation may include a cessation in flow or a reduction in a flow rate of the HM through the heat exchanger. The abnormal operation may include or be caused by a shutdown of the
10 pump, an accidental closure of a valve by a user, and the like. Moreover, during the abnormal operation, the exhaust gas may continue to flow across the coils. Lastly, the WHRU may include a control system to detect the abnormal operation, and to automatically isolate the waste heat recovery unit from the users and to facilitate implementation of removal of the HM from the heat exchanger during the abnormal operation.

15 **[0082]** While the present techniques may be susceptible to various modifications and alternative forms, the exemplary embodiments discussed above have been shown only by way of example. However, it should again be understood that the techniques is not intended to be limited to the particular embodiments disclosed herein. Indeed, the present techniques include all alternatives, modifications, and equivalents falling within the true spirit and scope
20 of the appended claims.

CLAIMS

What is claimed is:

1. A heat recovery system comprising:
 - a tube bundle having multiple tubes;
 - 5 an enclosure housing at least a portion of the tube bundle, wherein the enclosure is configured to receive a vapor and pass the vapor over the tube bundle;
 - a pump configured to flow a heating medium through the tube bundle to one or more users;
 - a control system configured to detect an abnormal operation of the heat recovery
 - 10 system, wherein the abnormal operation comprises a reduction of flow of the heating medium below a predetermined range of flow values; and
 - a collection system configured to reduce thermal degradation of the heating medium during the abnormal operation by evacuating the heating medium from the tube bundle during the abnormal operation.
- 15 2. The heat recovery system of claim 1, wherein the enclosure comprises ductwork.
3. The heat recovery system of claim 1 or claim 2, wherein the vapor comprises exhaust gas from a source outside of the heat recovery system.
4. The heat recovery system of claim 1 or any of claims 2 to 3, wherein the abnormal operation comprises a shutdown of the pump.
- 20 5. The heat recovery system of claim 1 or any of claims 2 to 4, wherein the abnormal operation comprises continued flow of the vapor across the tube bundle in the enclosure.
6. The heat recovery system of claim 1 or any of claims 2 to 5, wherein the collection system comprises a collection vessel configured to accumulate the heating medium removed from the multiple tubes during the abnormal operation.
- 25 7. The heat recovery system of claim 1 or any of claims 2 to 6, wherein the collection system is configured to evacuate the heating medium from the tube bundle without back-flushing the multiple tubes.
8. The heat recovery system of claim 1 or any of claims 2 to 7, wherein the collection system is configured to receive and vent heating medium vaporized in the tube bundle during
- 30 the abnormal operation.
9. The heat recovery system of claim 1 or any of claims 2 to 8, wherein the collection system comprises a purge gas inlet configured to pass purge gas through the tube bundle during the abnormal operation, wherein the purge gas is inert.

10. The heat recovery system of claim 1 or any of claims 2 to 9, comprising an ambient air inlet on the enclosure configured to introduce ambient air into the enclosure to dilute and reduce temperature of the vapor.
11. The heat recovery system of claim 1 or any of claims 2 to 10, wherein the tube bundle
5 comprises multiple tubes comprising coils.
12. A waste heat recovery unit comprising:
a heat exchanger;
a ductwork enclosing at least a portion of the coils, wherein the ductwork is
configured to receive and pass an exhaust gas over the heat exchanger;
10 a pump configured to circulate a heating medium through an internal flow path of the heat exchanger to absorb heat from the exhaust gas, and wherein the pump is configured to circulate the heating medium from the waste heat recovery unit to users of the heating medium;
a collection system configured to remove the heating medium from the heat
15 exchanger during an abnormal operation to reduce thermal degradation of the heating medium in the heat exchanger, wherein the collection system comprises a collection vessel configured to receive heating medium removed from the heat exchanger during the abnormal operation, and wherein the abnormal operation comprises a cessation of flow or substantial reduction in a
20 flow rate of the heating medium through the heat exchanger.
13. The waste heat recovery unit of claim 12, wherein the abnormal operation comprises a shutdown of the pump.
14. The waste heat recovery unit of claim 12 or claim 13, wherein the abnormal operation comprises continued flow of the exhaust gas across the heat exchanger.
- 25 15. The waste heat recovery unit of claim 12 or any of claims 13 to 14, wherein the collection system comprises a conduit configured to drain the heating medium from the heat exchanger to the collection vessel.
16. The waste heat recovery unit of claim 12 or any of claims 13 to 15, comprising a
30 control system configured to detect the abnormal operation, and configured to automatically implement removal of the heating medium from the coils during the abnormal operation.

17. A method of operating a waste heat recovery unit, the method comprising:
circulating a heating medium through multiple tubes of a tube bundle in the waste
heat recovery unit and to users of the heating medium outside of the waste
heat recovery unit;
- 5 passing a vapor over the tube bundle to transfer heat from the vapor to the heating
medium;
- detecting via a control system an abnormal operation of the waste heat recovery unit,
the abnormal operation comprising loss of circulation of the heating medium
through the multiple tubes; and
- 10 removing the heating medium from the multiple tubes to a collection vessel in the
waste heat recovery unit during the abnormal operation to reduce or avoid
thermal degradation of the heating medium.
18. The method of claim 17, wherein the vapor comprises exhaust gas.
19. The method of claim 17 or claim 18, comprising diluting the vapor with air to reduce
15 a temperature of the vapor during the abnormal operation.
20. The method of claim 17 or any of claims 18 to 19, wherein removing comprises
draining the heating medium from the multiple tubes to the collection vessel when the
heating medium is a liquid and venting the heating medium from the multiple tubes to the
collection vessel when the heating medium is a vapor.
- 20 21. The method of claim 17 or any of claims 18 to 20, comprising purging the multiple
tubes with an inert gas during the abnormal operation.
22. A method of constructing or retrofitting a waste heat recovery unit (WHRU) to
prevent or reduce thermal degradation of heating medium during abnormal operation of the
WHRU, the method comprising:
- 25 adding a conduit downstream of a tube bundle configured to transfer heat from an
exhaust gas to the heating medium, wherein the conduit is configured to divert
flow of the heating medium in the WHRU during the off-specification
operation of the WHRU, the abnormal operation comprising cessation of
normal flow of heating medium through the tube bundle;
- 30 installing a collection vessel coupled to the conduit and configured to receive heating
medium drained from the tube bundle via the conduit during the abnormal
operation; and

installing a valve on the conduit, wherein the valve is configured to isolate the collection vessel during normal operation of the WHRU and to place the collection vessel in service during the abnormal operation.

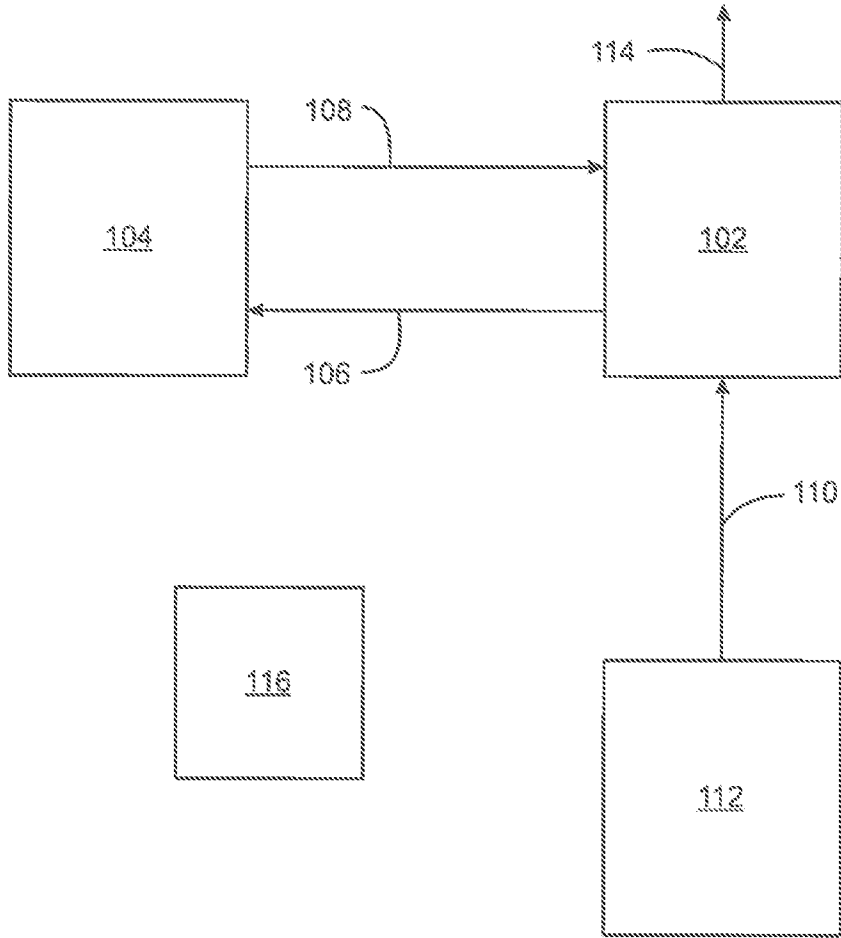
23. The method of claim 22, comprising installing an inert-gas purge inlet configured to provide an inert gas purge through tubes of the tube bundle during the abnormal operation.

24. The method of claim 22 or claim 23, comprising installing another conduit configured to receive vaporized heating medium from the tube bundle during the abnormal operation.

25. The method of claim 22 or any of claims 23 to 24, comprising installing an ambient-air inlet on ductwork receiving the exhaust gas and housing the tube bundle.

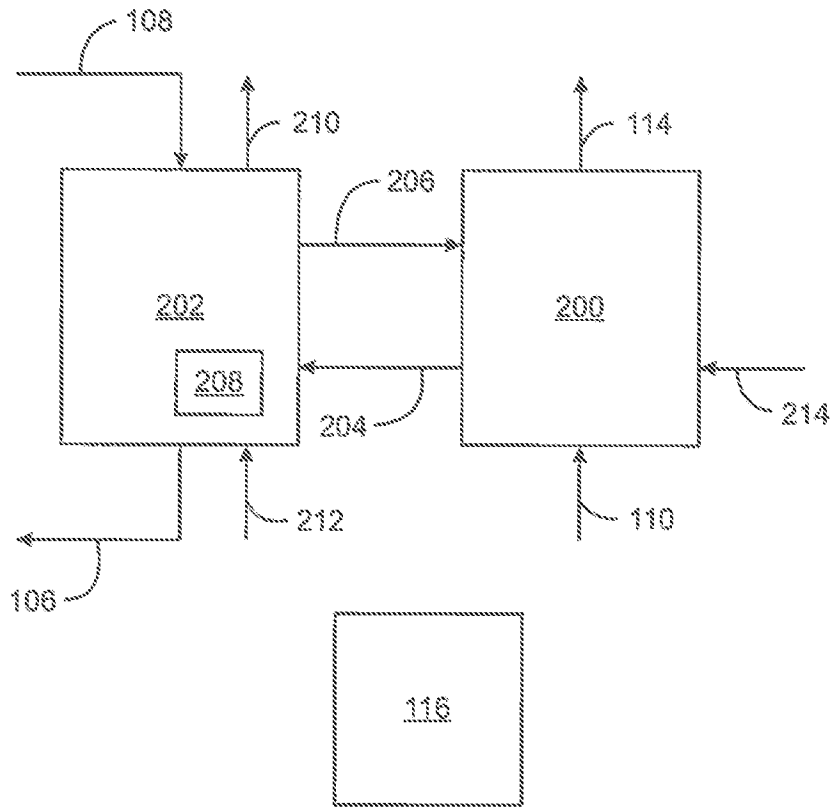
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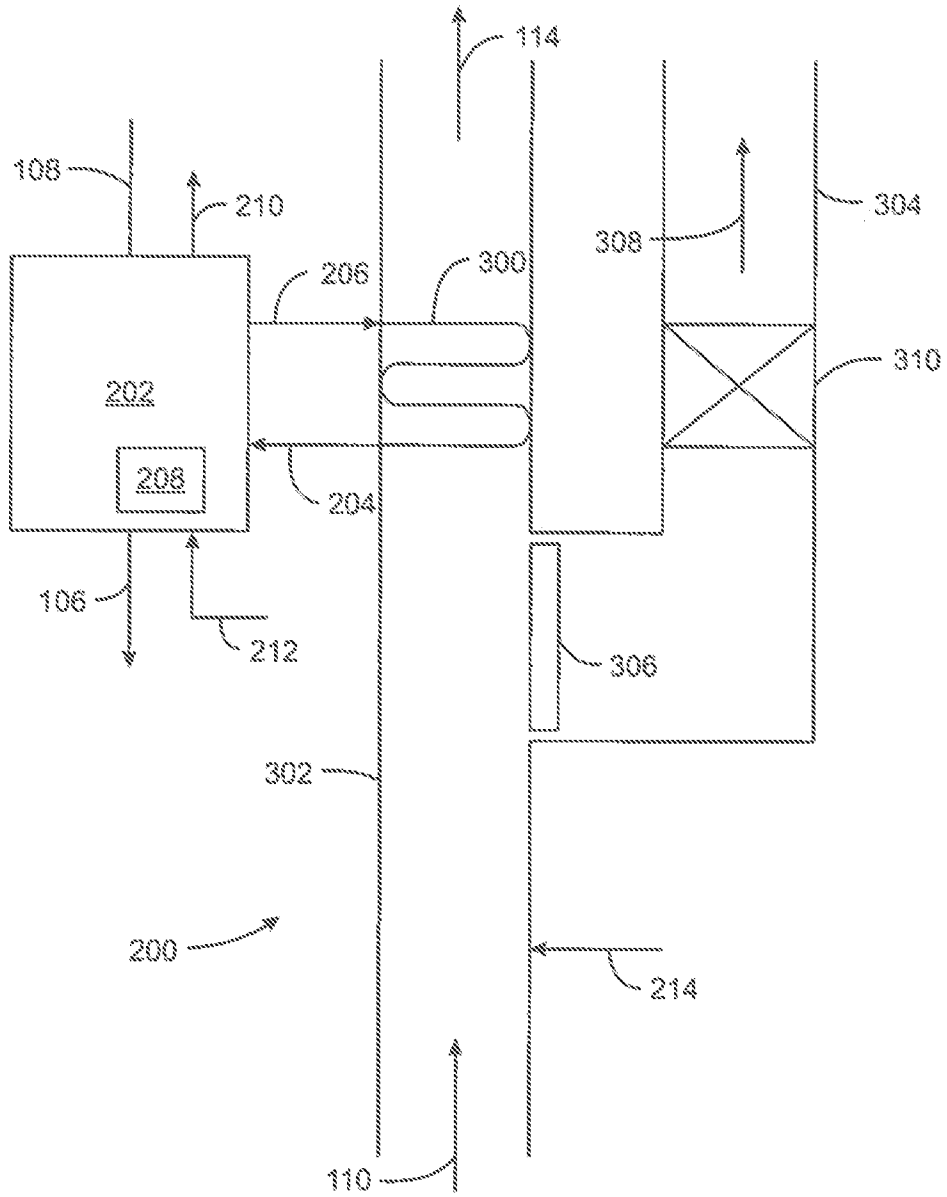
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FIG. 1

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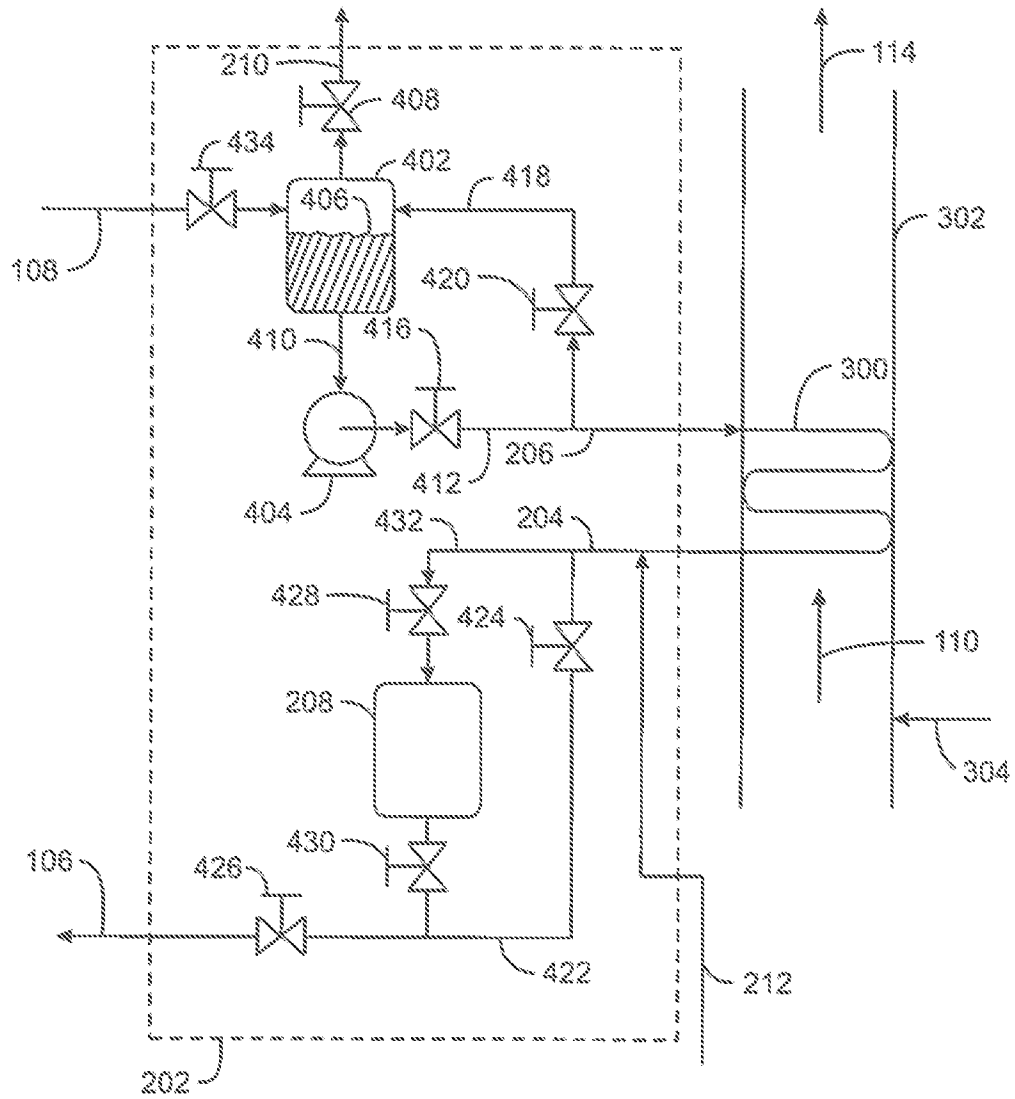
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FIG. 2

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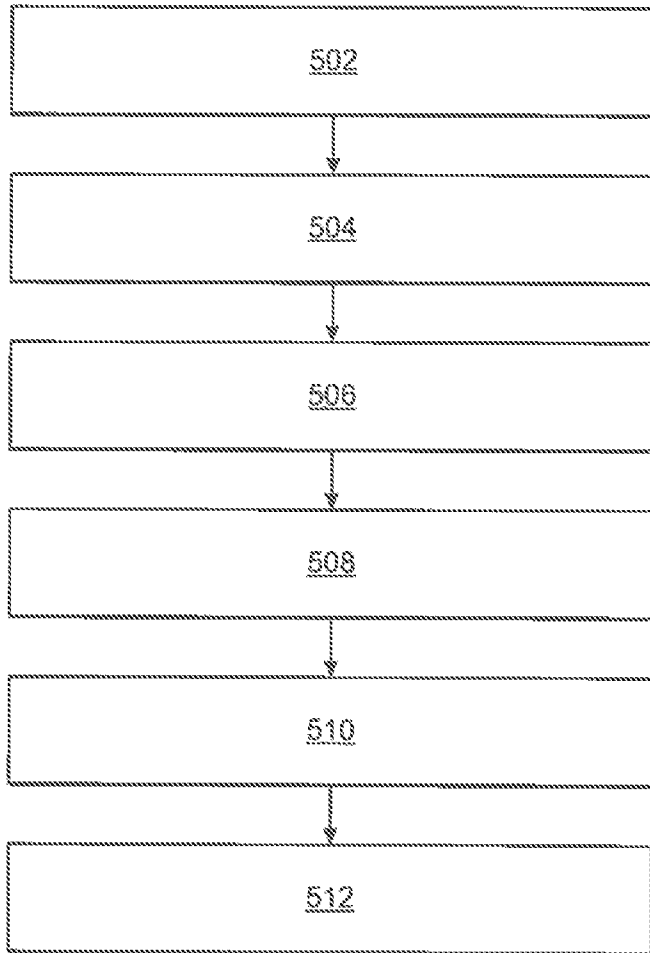
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FIG. 3

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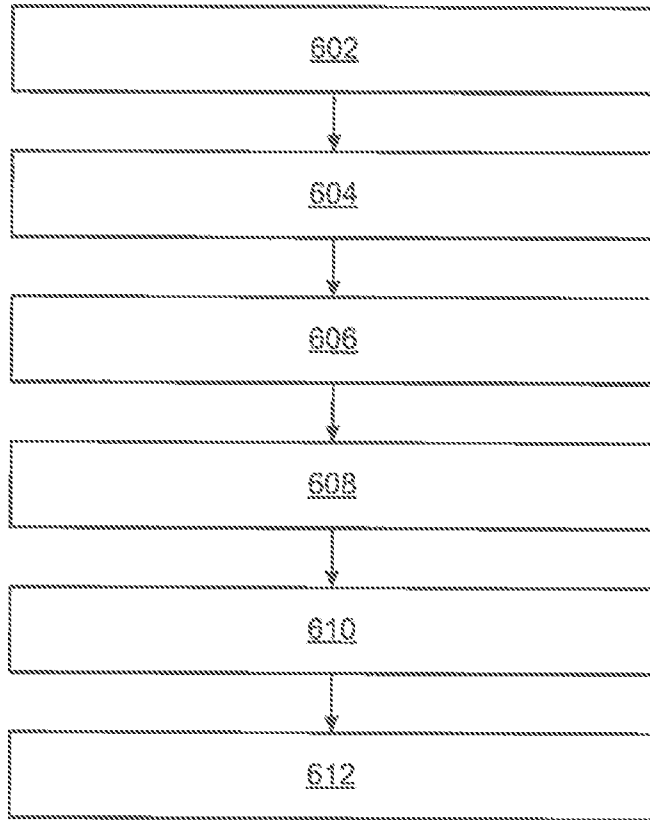
102
FIG. 4

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FIG. 5

6/6



600
FIG. 6

INTERNATIONAL SEARCH REPORT

International application No PCT/US2015/037319

A. CLASSIFICATION OF SUBJECT MATTER INV. F01K25/02 F28F19/00 F28F27/00 F28D15/00 ADD.				
According to International Patent Classification (IPC) or to both national classification and IPC				
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) F01K F28F F28D F24D F24J				
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched				
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data				
C. DOCUMENTS CONSIDERED TO BE RELEVANT				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.		
Y	US 2010/257882 A1 (PENEV KRASSIMIRE MIHAYLOV [US] ET AL) 14 October 2010 (2010-10-14) paragraph [[0044]]; figure 1 -----	1-25		
Y	CA 2 601 162 A1 (VERWAY JOHN A [CA]) 10 April 2009 (2009-04-10) figure 1 -----	1-25		
A	US 2011/016863 A1 (ERNST TIMOTHY C [US]) 27 January 2011 (2011-01-27) paragraph [0015]; figure 1 -----	12,22		
A	EP 2 040 013 A2 (BOSCH GMBH ROBERT [DE]) 25 March 2009 (2009-03-25) paragraph [0004] -----	1,12,17, 22		
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<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.				
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Date of the actual completion of the international search	Date of mailing of the international search report			
24 September 2015	02/11/2015			
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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/037319

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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